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FOR FLIGHT CONTROL(U) AIR FORCE AEROSPACE MEDICAL
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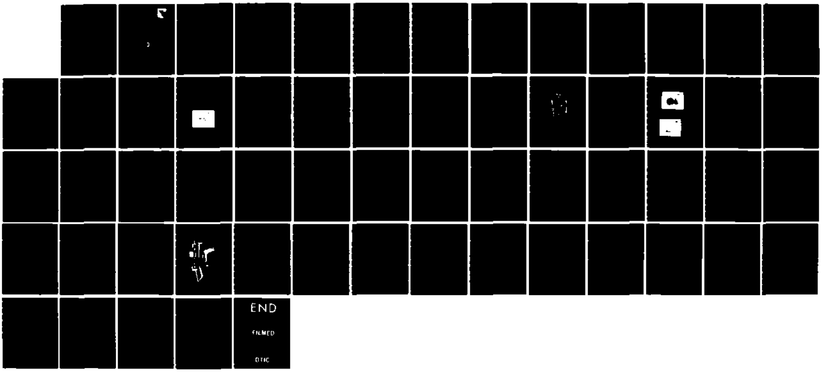

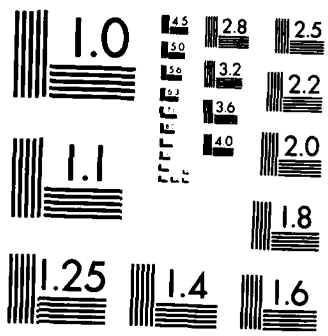

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MYOELECTRIC CONTROL OF A COMPUTER BASED EXPERT SYSTEM FOR FLIGHT CONTROL

DR. DANA B. ROGERS
MR. PHILIP B. GLAESER

APRIL 1985

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
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AFAMRL-TR-85-028

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Services (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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FOR THE COMMANDER

James C. Rock

JAMES C. ROCK, LT COL, USAF, BSC
Associate Director
Biodynamics & Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFAMRL-TR-85-028	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Aerospace Medical Research Lab, AFSC, AMD 6b. OFFICE SYMBOL (If applicable) AFAMRL/BBS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Wright-Patterson AFB OH 45433-6573	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62202F			

11. TITLE (Include Security Classification) MYOELECTRIC CONTROL OF A COMPUTER BASED EXPERT SYSTEM FOR FLIGHT CONTROL

12. PERSONAL AUTHOR(S)
Dr Dana B. Rogers Mr Philip B. Glaeser

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Technical	FROM ______ TO ______	April 1985	51

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The United States Air Force is constantly searching for new ways to transfer information between humans and machines. This goal becomes especially important in situations when conventional communication channels are overloaded or even inoperable. This document describes the results of a research effort to determine the possibility of using electromyographic signals to interface with a computer based expert system. The equipment described here is intended to demonstrate the feasibility of this type of control and facilitate future studies.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
R. E. VAN PATTEN	(513) 255-5742	AFAMRL/BBS

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE

ABSTRACT

MYOELECTRIC CONTROL OF A COMPUTER BASED EXPERT SYSTEM FOR FLIGHT CONTRTOL

The United States Air Force is constantly searching for new ways to transfer information between humans and machines. This goal becomes especially important in situations when conventional communication channels are overloaded or even inoperable. This document describes the results of a research effort to determine the possibility of using electromyographic signals to interface with a computer based expert system. The equipment described here is intended to demonstrate the feasibility of this type of control and facilitate future studies.

This work was supported by the Aerospace Medical Research Laboratory (USAF) under contract number F30602-81-C-0206

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INTRODUCTION

An electromyographic or EMG signal describes the electrical voltage which exists in an active muscle. Myo is a Greek word for muscle. The electrochemical reactions which are involved in the contraction of a muscle produce this voltage. The analysis of this signal has been used for many purposes including prosthesis control and bioelectric feedback. Prosthesis applications have shown that EMG signals can be used for the voluntary control of artificial limbs. Bioelectric feedback has been used to train airplane pilots to perform straining maneuvers under high G forces. Straining maneuvers are used in order to prevent temporary vision loss by the pilot.

Since the EMG signal still exists at high G forces, and can be voluntarily controlled, it should be possible to use the EMG as a means of controlling external devices under high G forces. Under conditions when even motion is difficult, this form of communication can still provide a working channel between human and machine.

This document describes a laboratory myoelectric control system which can detect activity in muscles and convert these signals into a digital format. The muscle inputs can then be used for computer control. The purpose of this thesis is to show that this type of control does work. In addition, this system is designed with features that would enable its operation under high G forces. The block diagram for the myoelectric control system is shown in figure 1.

Chapter I describes methods of analyzing the raw EMG signal. By examining the different approaches, a method of processing the EMG for this system is proposed. The description of the actual hardware design is the subject of Chapter II.

Chapter III introduces the speech capabilities of the system. Both the need for voice feedback and the operation of the actual hardware are discussed.

The system is based around a Zenith Z-100 microcomputer. The Zenith supports an S-100 bus system which provides expansion slots for S-100 breadboards. All of the interface between the Zenith and additional hardware is done via the S-100 bus. The details of how data is exchanged between the Zenith and the breadboards are explained in Chapter IV.

The software that controls the entire system is important for two reasons. First, the software must maintain complete control of the hardware in order to ensure reliable operation. Secondly, it must be able to effectively use the information it receives in order to make useful system decisions. Both aspects of the software are brought out in Chapter V.

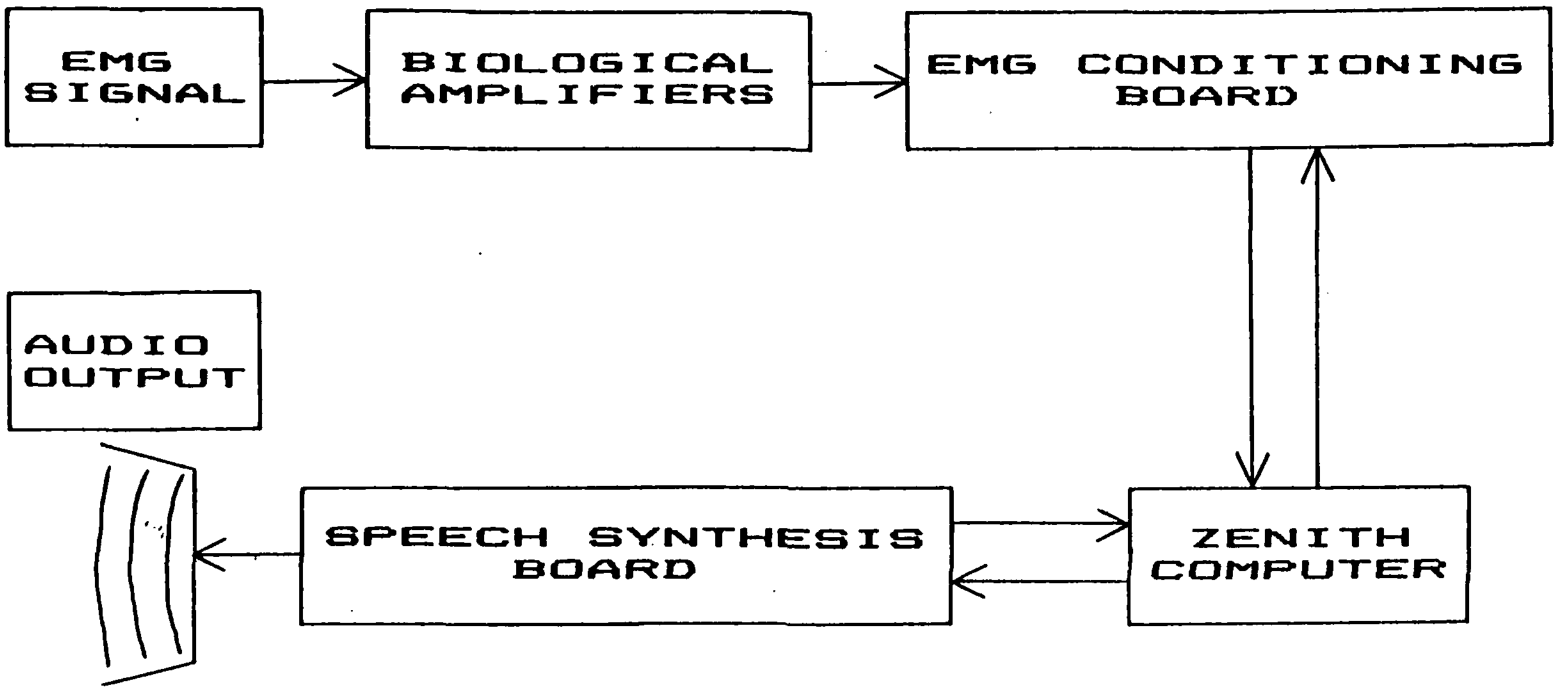

Figure 1. Myoelectric Control System Block Diagram

Chapter VI contains descriptions and results of experiments to test the system. Chapter VII contains conclusions and recommendations for possible future applications of this system.

The output of the integrator is then fed into the comparator shown in figure 14. The circuit compares the input voltage to a threshold value. The comparator output will be twelve volts when the integrator voltage is above the threshold and zero volts when it is not.

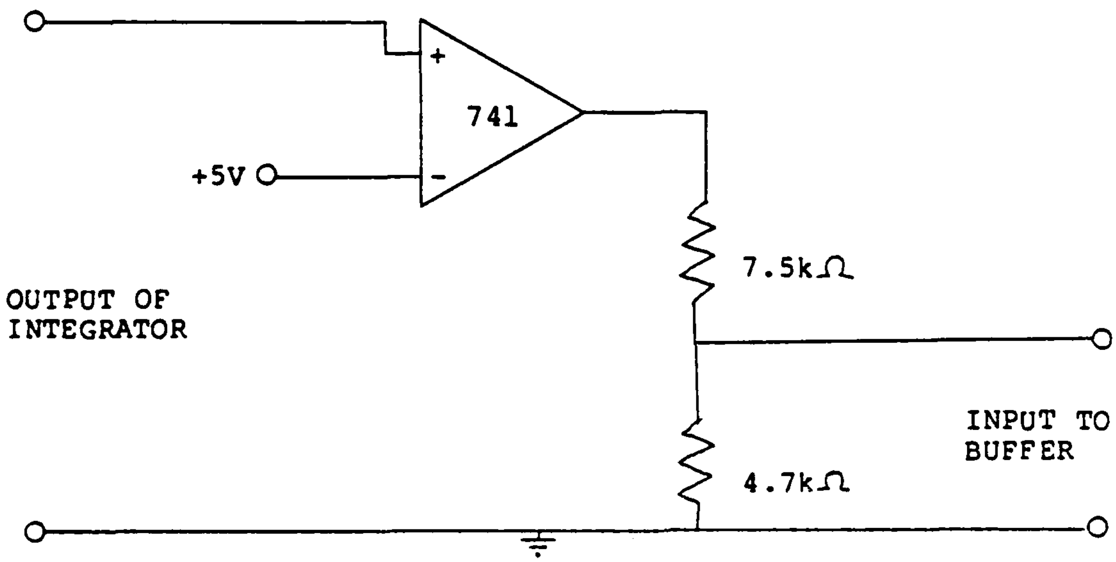

Figure 14. Comparator/Voltage Divider

The comparator output is sent through a voltage divider to reduce the twelve volts to five volts. The signal is now either zero or five volts and can be read by the Zenith. The last stage is a buffer which isolates this signal from the data lines on the Zenith. The Zenith can activate the buffer and read the information. A "1" input represents activity while a "0" input represents no activity.

the filter because rectifying produces harmonics. It is easier to eliminate the low frequencies of the original signal then to eliminate the higher frequency harmonics. The rectifier is necessary in order to insure the desired operation of the integrator.

The signal is then fed into an integrator circuit which is also shown in figure 13. The integration of the negative input appears as a positive voltage across capacitor C1. The voltage on C1 is the output of the integrator. The rate at which the capacitor will build up voltage depends on the strength of the input signal. There is also an electronic switch across the capacitor. The Zenith can open and close this switch by writing a "0" or "1" to a data latch. The switch is used to short out the capacitor voltage thereby resetting the output of the integrator to zero volts.

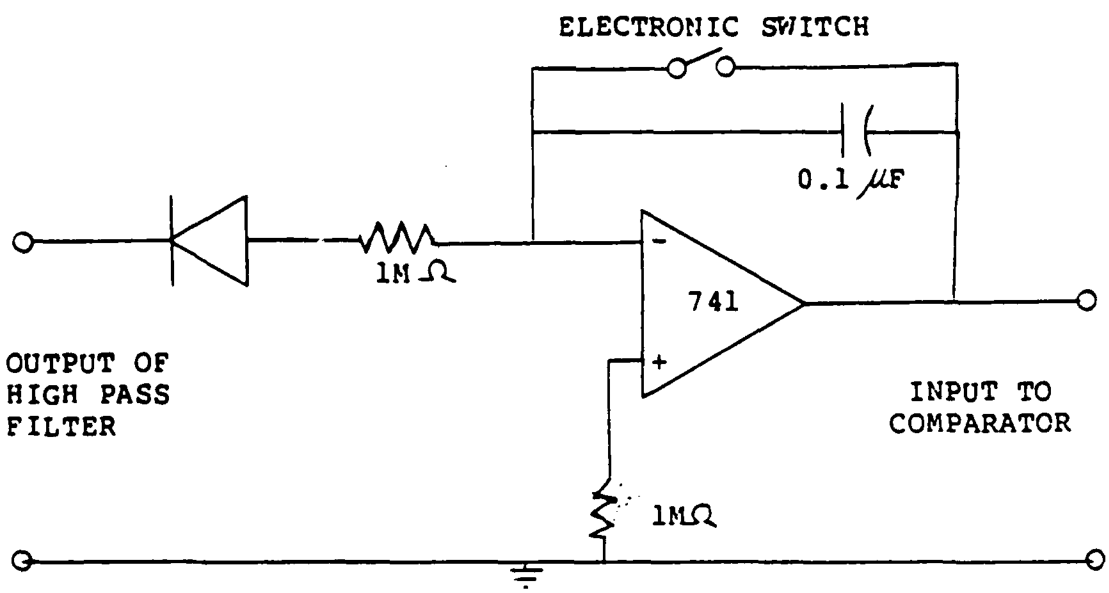

Figure 13. Rectifier/Integrator

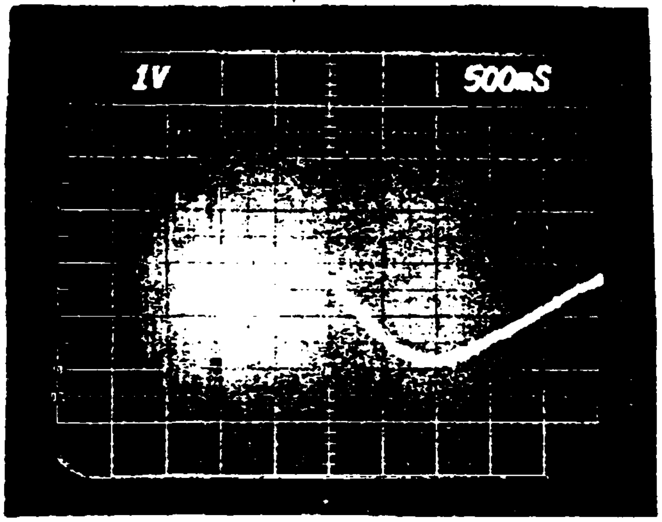

Figure 11. EMG Signal: Tense-Relaxed

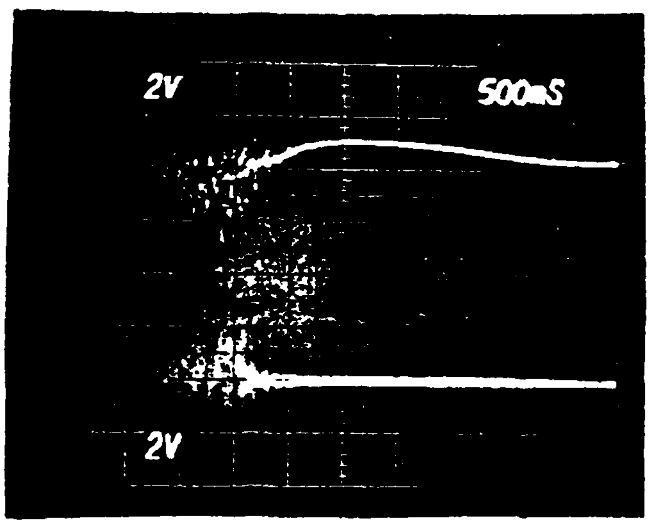

Figure 12. Before-After Filter Comparison

noise that is inherent to the bioelectric amplifiers. This also eliminates the low frequencies from the muscle signal, but there is enough of the signal present between 200 and 400 Hertz for signal detection. Both these problems are solved by using a two pole highpass filter with a cutoff frequency of 150 Hertz. Figure 12 shows the comparison of the EMG signal before and after the filter.

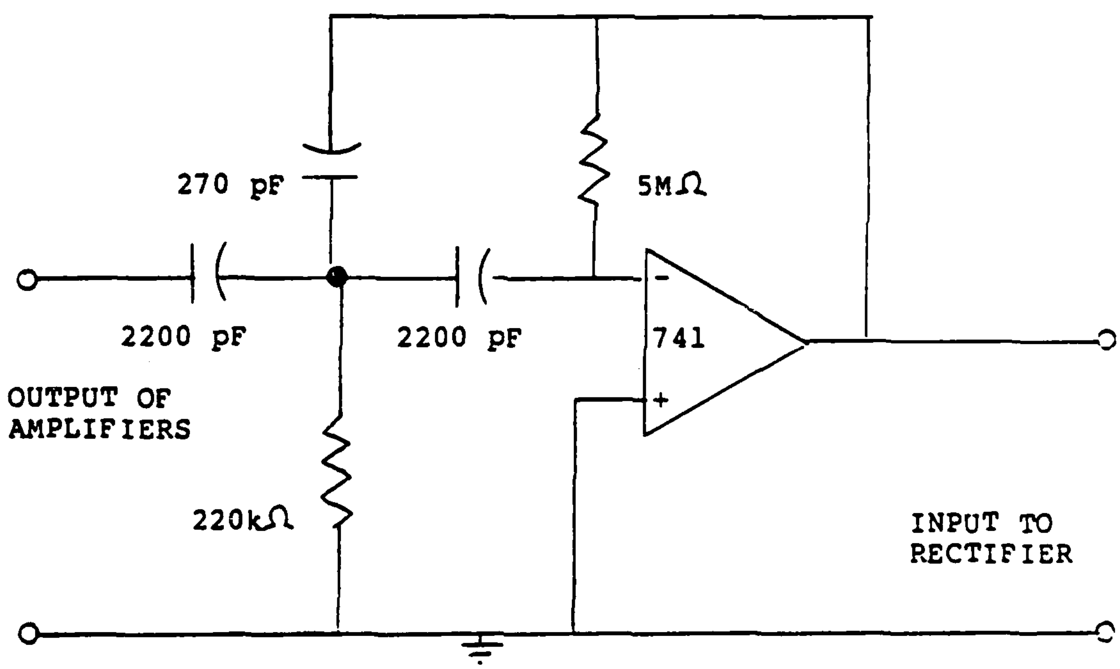

Figure 10. High Pass Filter

The output of the filter is half-wave rectified with a diode as shown in figure 13. The positive portion of the signal is suppressed. It is advantageous to rectify after

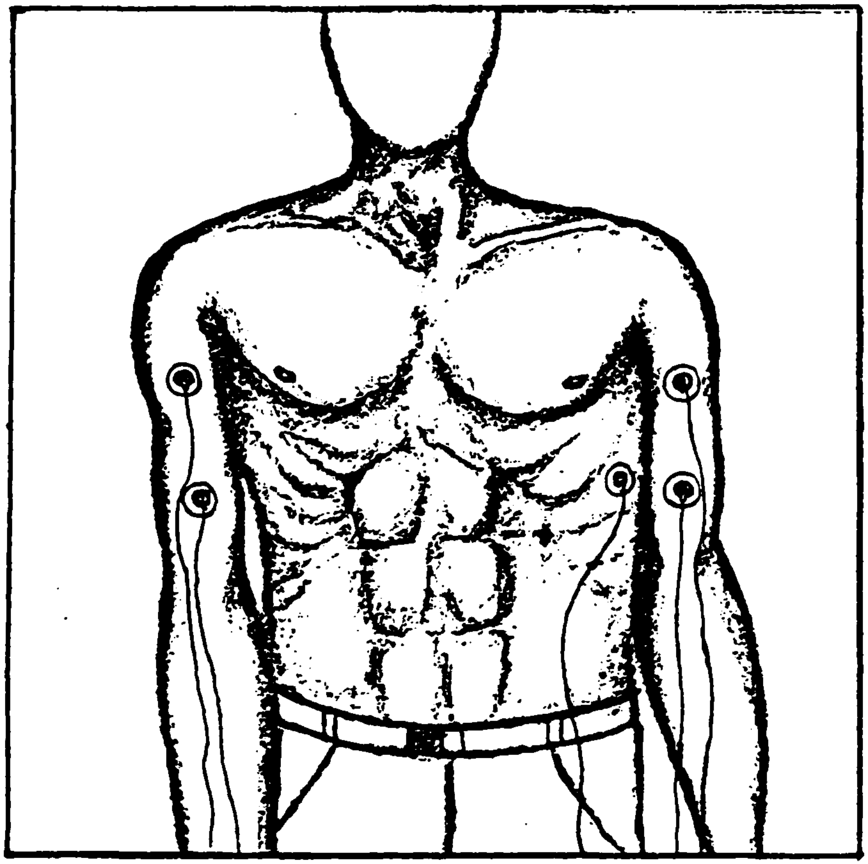

Figure 9. Electrode Placement

The signal is first run through a highpass filter shown in figure 10. This is done for two reasons. First, it is necessary to eliminate very low frequencies, DC to 5 Hertz, from the signal. The reason for this is that a large voltage around these frequencies occurs when the muscle is released as shown in figure 11. Since a signal is wanted only when the muscle is tense, these low frequencies must be rejected. It is also desirable to eliminate the 60 Hertz

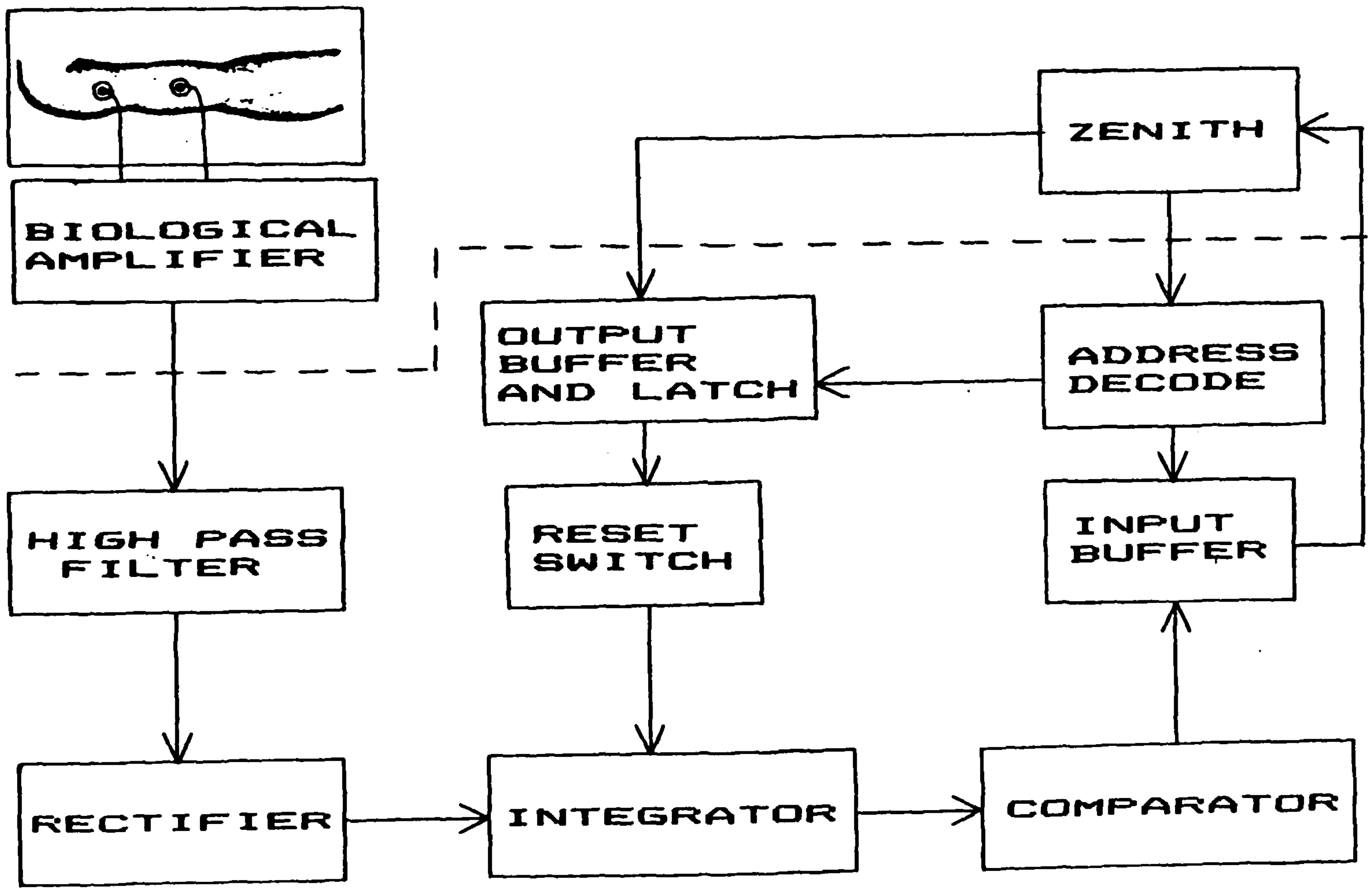

Figure 8. EMG Conditioning Board Block Diagram

CHAPTER II

EMG CONDITIONING BOARD

The EMG conditioning circuitry is built on a S-100 breadboard. The interface with the computer makes it easy to add another design consideration to the EMG detection process, flexibility. By designing the board to operate under software control, adjustments in the system are made by simple program changes. This chapter discusses all the details of the EMG processing.

The block diagram for this board is shown in figure 8. The EMG signals are taken from the biceps. The biceps provide a good signal, greater than 10 millivolts, and are easy to control. Two electrodes are placed across the belly of each muscle as shown in figure 9. A fifth electrode is placed on the side of the ribs and is used for a reference. When the bicep is tense, a voltage potential is developed between the two electrodes on the bicep. This raw signal is amplified by a factor of 10,000 using a standard bioelectric amplifier. The signal is brought to the interface board for processing. Each muscle signal is run through identical but separate channels.

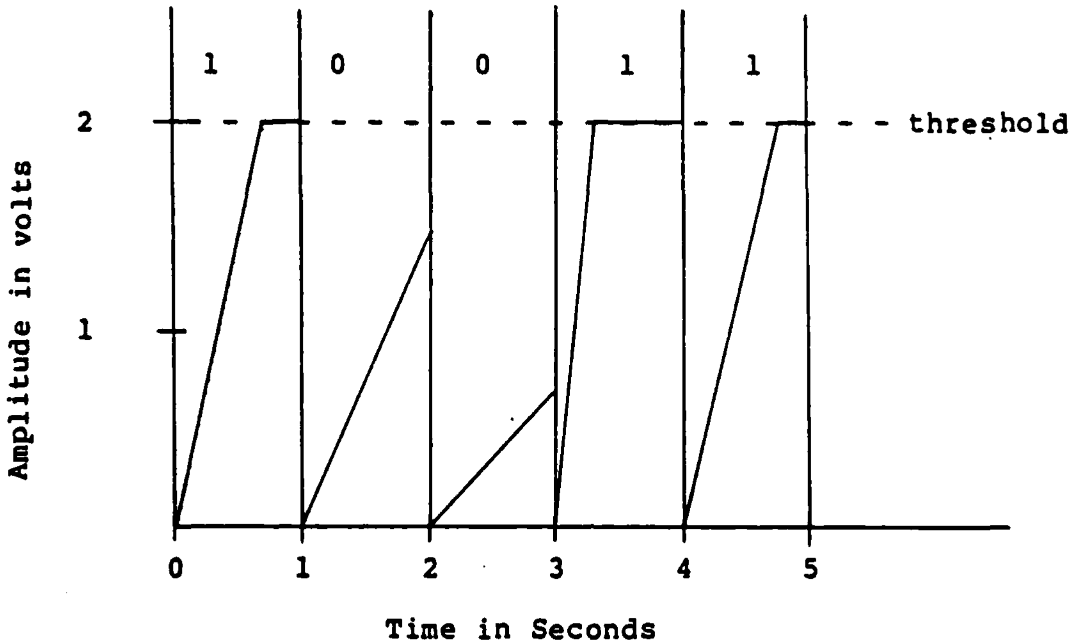

Figure 7. Integrator Analysis- Constant Time Period

The myoelectric control system developed in this paper uses the last approach. Since the input is done by simply holding a muscle tense, it is easy to learn. The reliability is largely dependent on preventing noise from affecting the system. The hardware designed to implement this method is described in the following chapter.

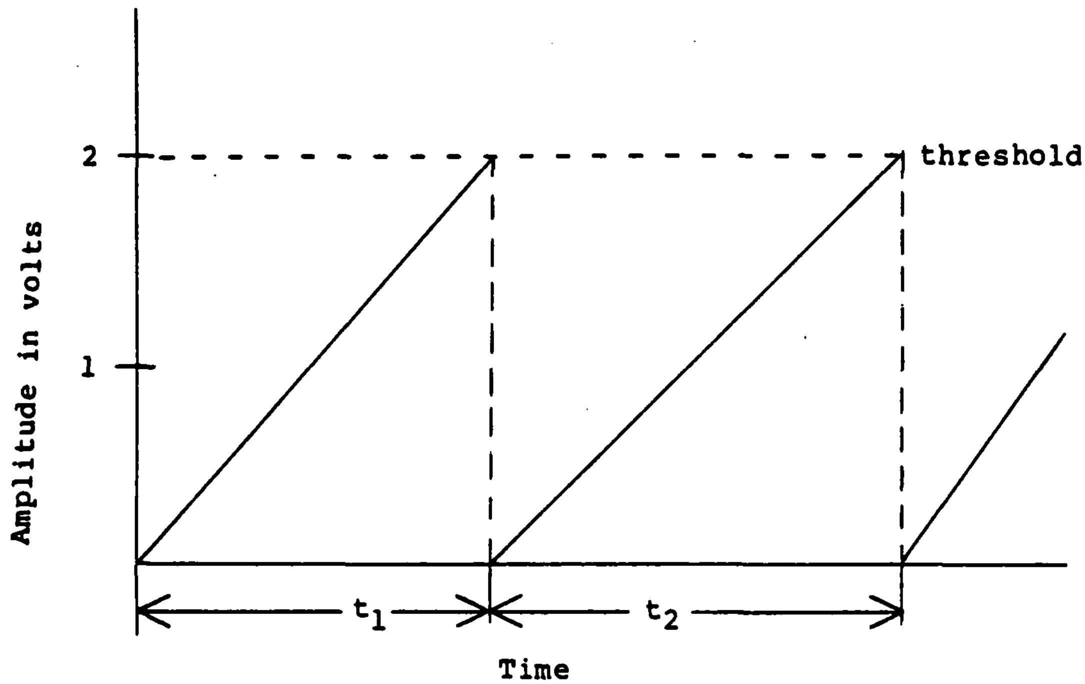

Figure 6. Integrator Analysis- Variable Time Period

The second approach uses a constant time period and records a "1" if the threshold value was reached and a 0" otherwise. See figure 7. This method is feasible if you use at least a two channel system. With two channels, it is possible to consider a "1" as an input and a "0" as no input. Two channels would then allow for two inputs. This eliminates the problem of precise control of the EMG output because exact timing between inputs is not needed. The system will only react if an input is received.

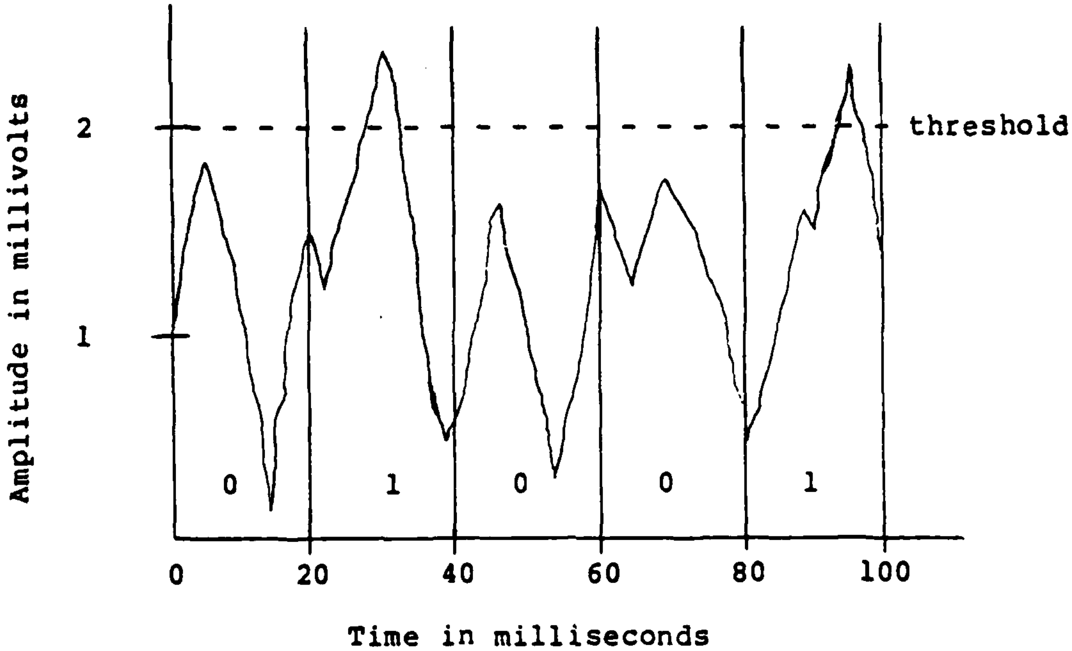

Figure 5. Comparator Analysis

The use of an integrator is also a possible approach. A voltage present on the integrator is compared to a threshold value. The integration rate provides a delay between the time when a muscle is active and when it is actually detected.

There are two possible approaches using an integrator. The first would use the time between the points when the consecutive thresholds were reached to represent the input. See figure 6. Again, this method proves unreasonable because of the difficulty in exact control of the EMG output.

Amplitude Analysis

Amplitude analysis looks at the total voltage output at any time. This voltage swings positive and negative so it is first rectified before further processing. A typical EMG signal is shown in figure 4. A few different types of analysis fall under this category. These methods produce a serial output from one muscle. A parallel coding technique could be obtained by using the single outputs of multiple muscle groups.

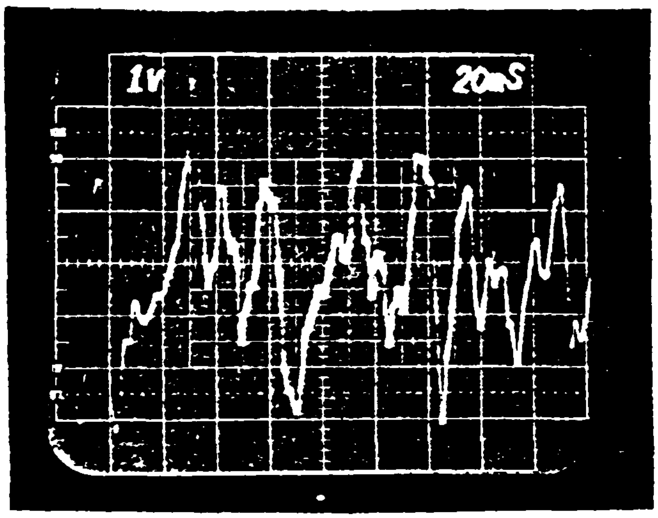

Figure 4. Typical EMG Signal

Another approach compares the output to a threshold level as shown in figure 5. Again, the difficulty in exactly controlling the amplitude and frequency of the EMG makes this method unreasonable.

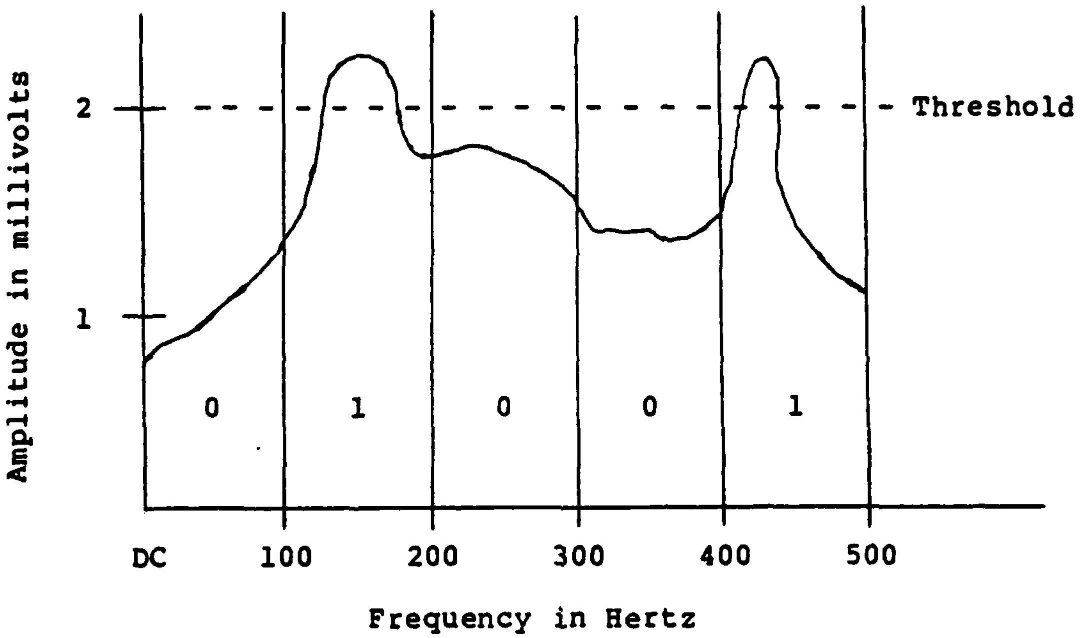

Figure 3. Frequency Bin Analysis

It is possible for one to control the frequencies of one's EMG signal but there are some limitations. First, certain ranges of frequency always exist and it is not easy to control their amplitudes. Secondly, the major frequency conponents in a muscle are dependent on many factors. The size of the muscle, the amount of fatigue, and changes from person to person all affect the frequencies present. In general, an application of this kind would probably be hard to learn.

One approach is to determine the center frequency of the signal, where different center frequencies would represent different digital inputs to the system as shown in figure 2.

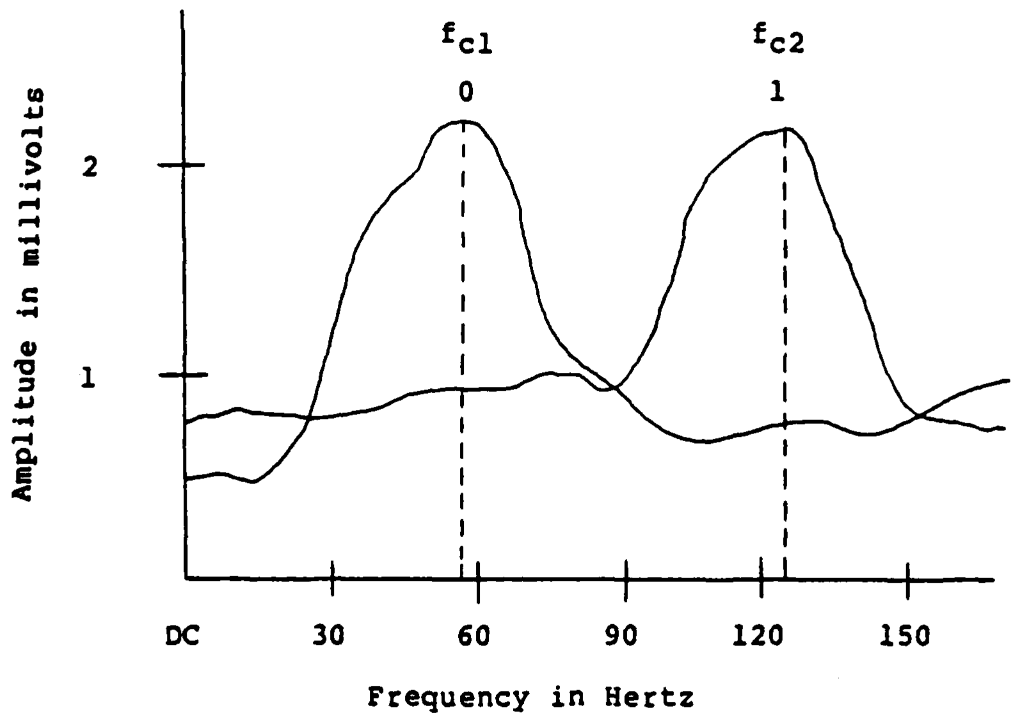

Figure 2. Center Frequency Analysis

A second approach to frequency analysis divides the spectrum into bins as in figure 3. Each bin represents a single bit in a multiple bit binary code. Each bin with an output over a certain threshold value would represent a "1" while those below the threshold value would represent "0". This method would provide a parallel binary input from a single muscle group.

CHAPTER I

EMG SIGNAL PROCESSING

The detection and processing of the EMG signal is the most important aspect of the system. The method chosen must be reliable. In addition, the operation of the system needs to be easy to learn and perform. By meeting these conditions, the system will be effective in a variety of environments.

An EMG signal has an amplitude of a few millivolts and contains various frequencies concentrated between DC and 400 Hertz. The center frequency is usually between 50 and 70 Hertz. Many methods of analyzing the signal are available. An overview of a few of these methods will develop a feel for the problems involved in analyzing the EMG.

Frequency Analysis

Frequency analysis involves determining the amplitudes of each frequency component in the signal. This can be done, for example, by analog filters, digital filters, or a Fourier transform process. Two methods of interpreting the results are discussed here.

CHAPTER III

SPEECH SYNTHESIS BOARD

The user needs feedback to help him maintain control of the system. In addition to the visual feedback on the monitor, an audible feedback of high quality speech is also provided. Audio is included for two reasons. First, it does not require constant attention. The user can be concentrating on other tasks and still have immediate knowledge of the system's activity. Secondly, the eyes fail at a lower G level than the ears. Under high G conditions, a speech system may be the primary form of feedback.

The speech synthesis board is based on the TMS 5220 voice synthesis processor (VSP), and its associated memory chip, the TMS 6100 voice synthesis memory (VSM). The TMS 5220 uses linear predictive coding to produce high quality speech. The TMS 6100 is a 128-kilobit ROM. The four ROMs in this system provide a vocabulary of over 450 words. This system is TTL compatible and easily interfaced to a microcomputer.

The block diagram of this circuit is shown in figure 15. (Note that D7 is the least significant data line on the TMS 5220.)

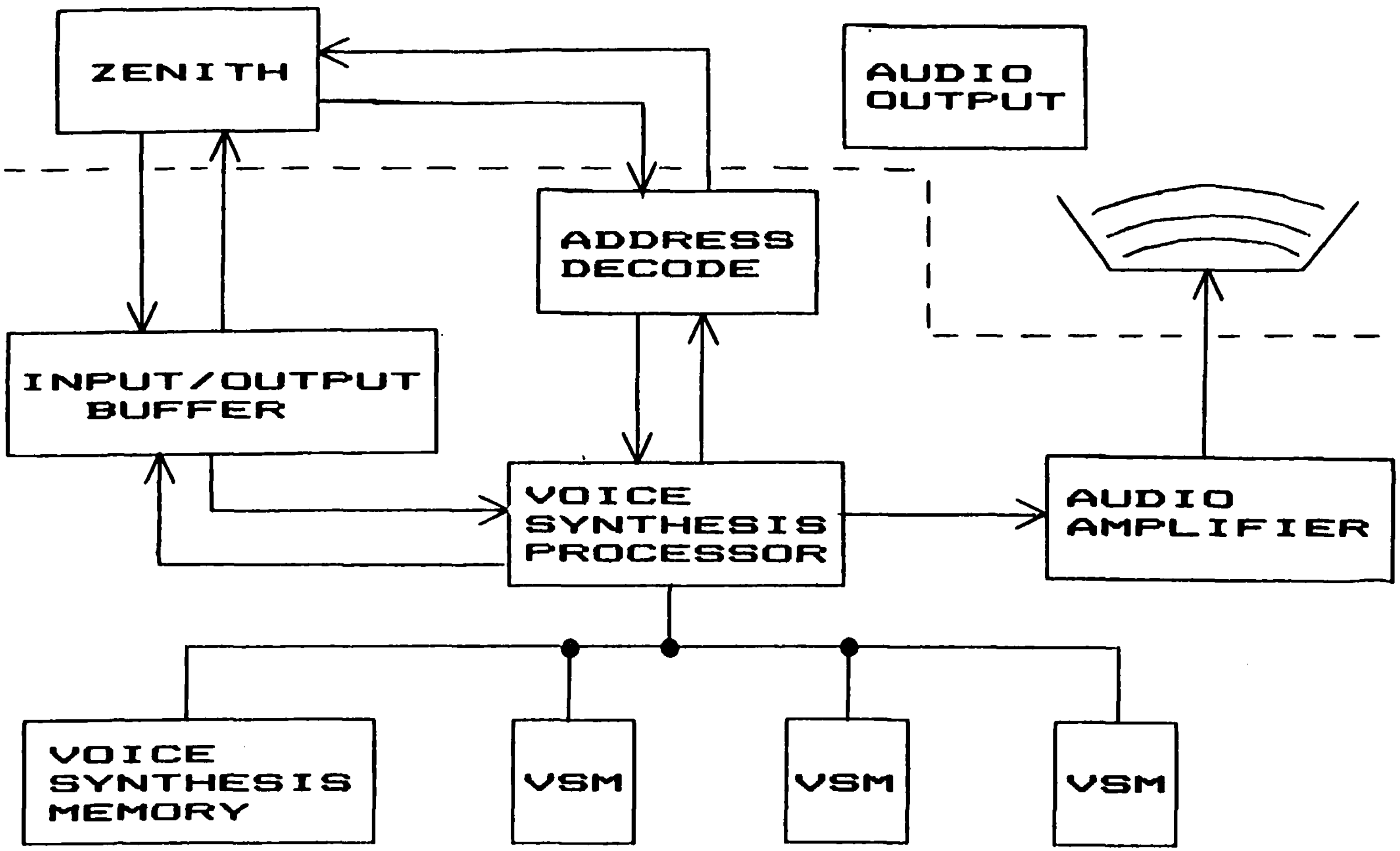

Figure 15. Speech Synthesis Board Block Diagram

To initiate speech, the Zenith sends four hexadecimal numbers to the VSP. These numbers represent a memory location in the VSM. The code for one word starts at this location. The Zenith then sends a "Speak" command and the VSP uses the addressed code to create an audio output. The Zenith continues to monitor the status of the VSP until the speech process is completed. The Zenith then resets the VSP and initiates another word or continues on with other programming.

CHAPTER IV

MICROCOMPUTER INTERFACE

For this system, the Zenith runs all software on an 8088 microprocessor. The 8088 also acts as the master of the S-100 bus. A master is the device which controls the bus. All other devices are controlled by the master and are called slaves. A slave receives data from or sends data to the bus master. Slaves are separated into two types, memory devices and input/output or I/O devices. Both the EMG conditioning board and the speech synthesis board are I/O devices.

Most signals on S-100 bus are either input or output lines. The master sends information out on the output lines and receives information on the input lines. In addition, one special utility line is used. The following lists each line used with its S-100 pin number and a description of its function.

Input Lines

DI0-DI7 (Data lines)	Pin Numbers: 95,94,41,42,91,92,93,43 Description: DI0-DI7 is an eight bit path to input data to the master. DI0 is the least significant bit.
RDY (Ready)	Pin Number: 72 Active: High Description: RDY is asserted high by a slave to tell the master it is ready to complete the current bus cycle.

Output Lines

A0-A7 (Address Lines)	Pin Numbers: 79,80,81,31,30,29,82,83 Description: A0-A7 is an eight bit path used to address slaves. A0 is the least significant bit.
DO0-DO7 (Data Lines)	Pin Numbers: 36,35,88,89,38,39,40,90 Description: DO0-DO7 is an eight bit path to output data from the master. DO0 is the least significant bit.
sINP (status INPut)	Pin Number: 46 Active: High Description: This line is active when the master is executing an input cycle and reading data from an I/O port address.
sOUT (status OUTput)	Pin Number: 45 Active: High Description: This status line is active when the master is executing an output cycle and writing data to an I/O port address.
pWR* (processor WRite)	Pin Number: 77 Active: Low Description: pWR* is used to tell the slave when the data on the data output bus is valid.
pDBIN (processor Data Bus IN)	Pin Number: 78 Active: High Description: pDBIN is used to tell the slave when to place its data on the data input bus.
pSYNC (processor SYNChronize)	Pin Number: 76 Active: High Description: This is a strobe that indicates the start of every bus cycle. It becomes active near the beginning of every bus cycle and remains active for one clock cycle.

Utility Line

POC* (Power On Clear)	Pin number: 99 Active: Low Description: POC* starts out low when the system powers up and remains low for at least 10 milliseconds. It is used to insure that all hardware is initiated in the proper state.

Each board has circuitry to decode the address lines as shown in figure 16. Each address line is connected to the input of an exclusive or gate. The other input to the gate is connected to a combination of a switch and a pull-up resistor. Considering a closed switch to represent logic 1 and an open switch logic 0, the signal on the address line must match the switch to create a high output from the exclusive or gate. The outputs of all eight gates are connected together along with a pull-up resistor. The output of all gates must be high in order for the board select signal, BDSEL, to be high.

The BDSEL signal is combined with status and control signals to determine the proper I/O operation. Figure 17 shows the read/write decode logic of the speech synthesis board. Similar circuitry is used on the EMG conditioning board except for the section labeled "Wait State Generator" which is only present on the speech board. This added circuitry is necessary because the VSP cannot transfer data as quickly as the 8088 can. The Wait State Generator delays the read or write cycle of the 8088 until the VSP is ready to complete the data transfer.

When read or write operation is decoded by a board, the buffer which isolates the computer's data lines from the board is taken out of the high impedance state. This connects the computer and board data lines together and transfer of information can take place.

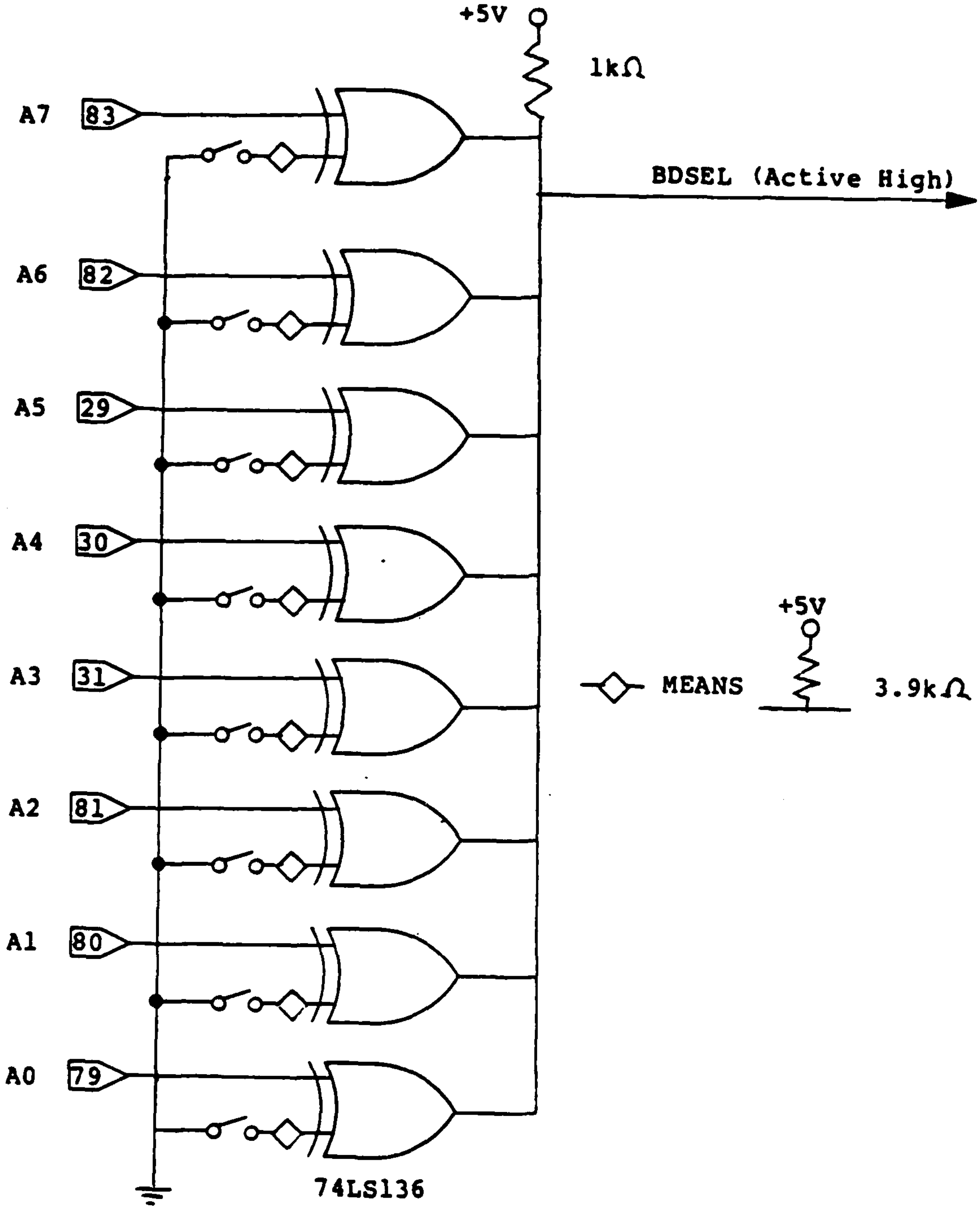

Figure 16. Address Decode Logic

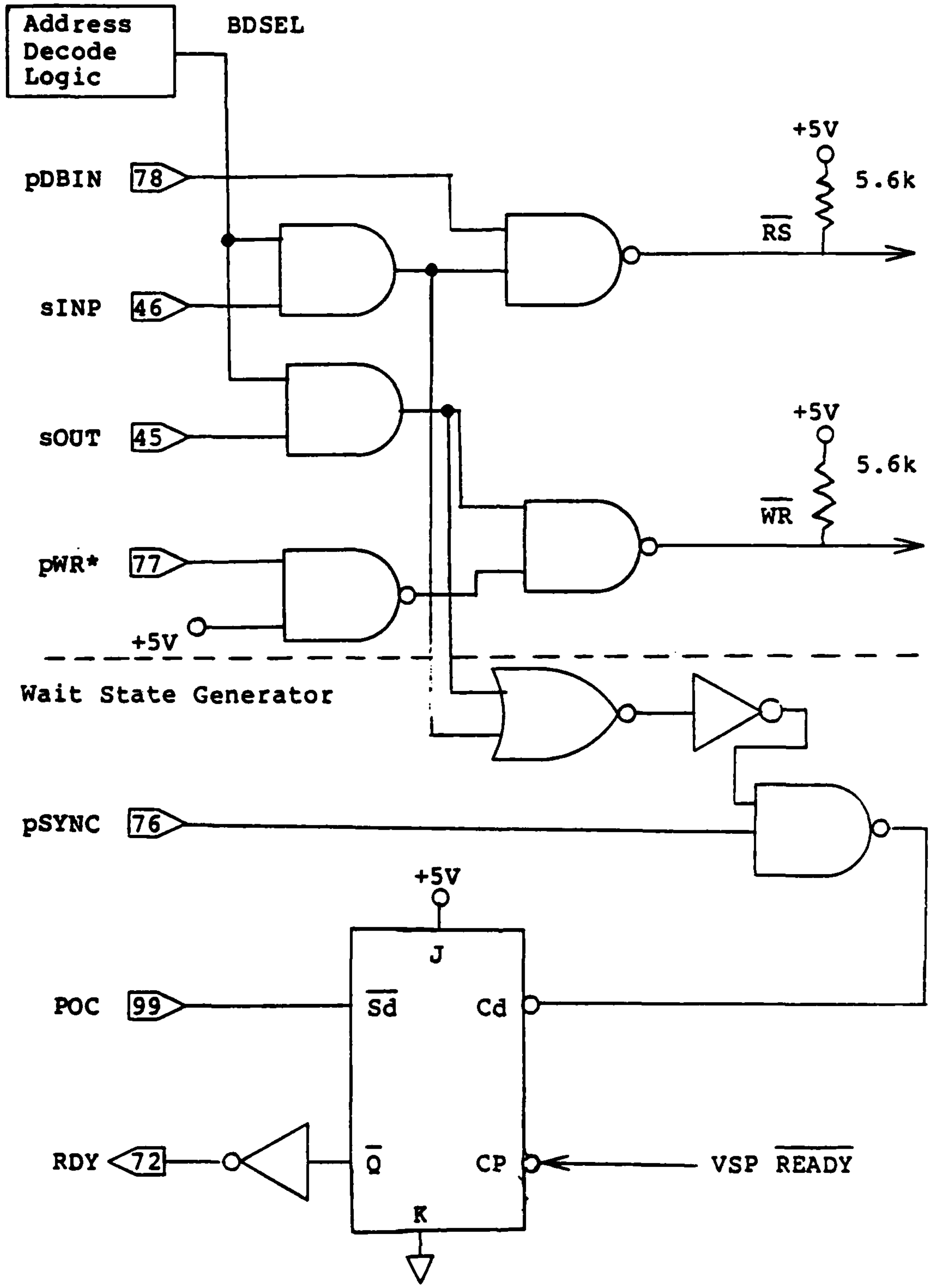

Figure 17. Read/Write Decode Logic

CHAPTER V

CONTROLLING SOFTWARE

The software for this system performs two functions. First, it controls the operation of both the EMG conditioning board and the speech synthesis board. Secondly, it uses the decision making ability of the Zenith in conjunction with the inputs from the EMG conditioning board to determine the system's output. In this manner, the Zenith is used as the basis of an expert system. This section reviews three programs and one algorithm which are used to test and run the system.

Program: SPK-WORD

SPK-WORD is short for Speak-word. It is an interactive program used to control the speech synthesis board. The program prompts the user to input the hexadecimal address of the word to be spoken. The program then manipulates the input into the form the VSP requires and outputs the data. The word is spoken and the program prompts for another input. The routines used in this program are used for all programs which make use of the speech synthesis board. A listing of this program is found in Appendix A.

EMG Input Algorithm

This algorithm controls the inputs from the EMG conditioning board. An input from this board is referred to as a "hit". This algorithm is flowcharted in figure 18. Its operation is also described below.

One flag variable is used for each channel. The algorithm initializes the system by resetting the flags, the integrator voltage, and a counter. The output of each channel is read in and checked for activity. If no activity is found, the counter is advanced. The counter is then checked to see if a limit is reached. If the limit was not reached, the program goes back and checks the output of each channel again. This process will continue if no input is present until the counter reaches its limit. The program will then go back to the start state. In this manner, the counter limits the amount of time the integrator has to build up voltage. This process proves to be very effective in stopping noise from activating the EMG board's output.

If activity is found on a channel, the flag for that channel is set to logical one. The program then resets the counter and the integrator voltage to zero and checks for more activity. If a channel is found to be active two times in a row, then a "hit" will be recognized on this channel. Using the flags forces the muscle to be tense for a longer period of time which helps prevent erroneous inputs.

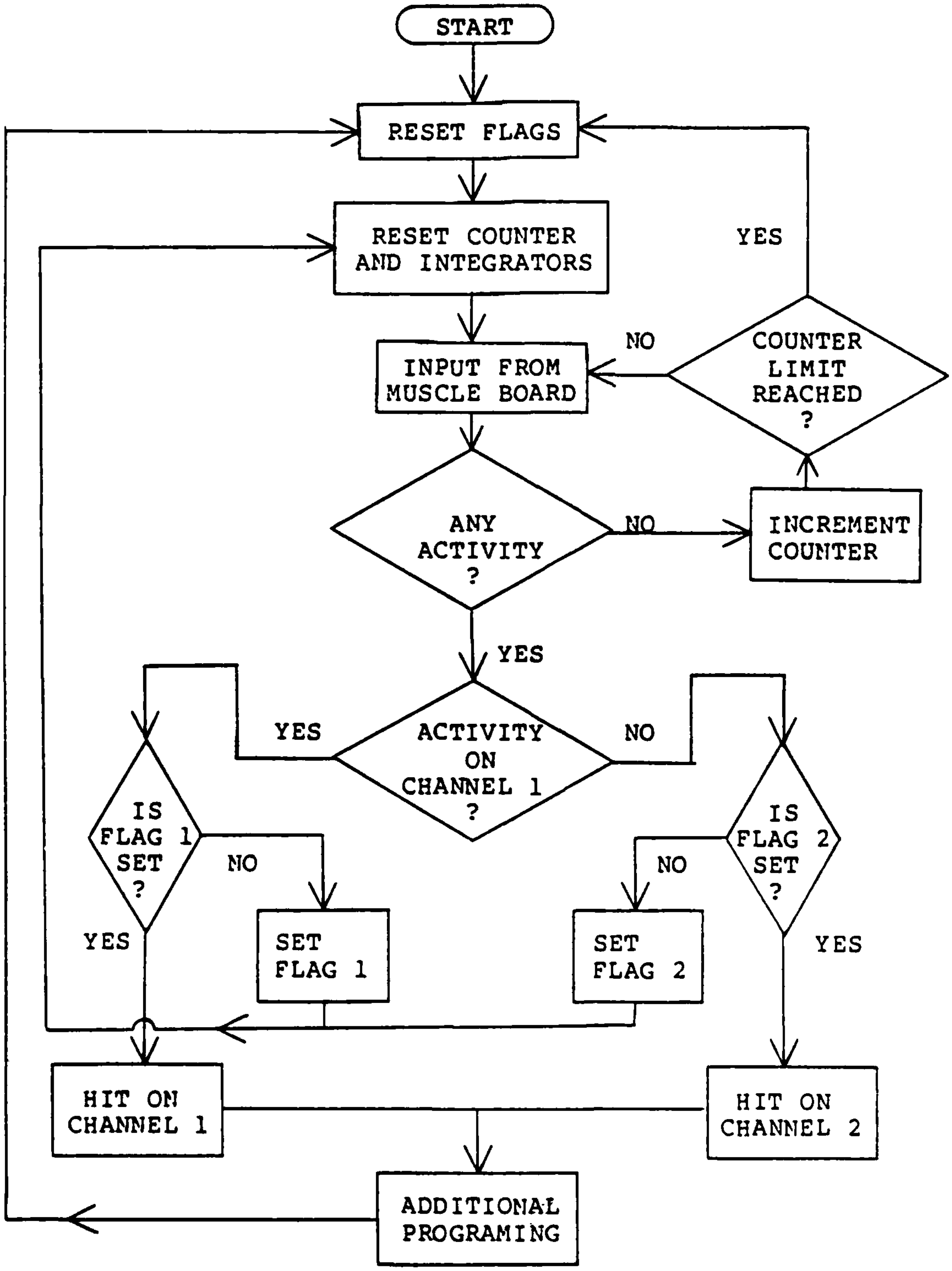

Figure 18. EMG Input Algorithm Flowchart

Program: INP2CH

INP2CH stands for Input two Channels. It is listed in Appendix A. This program enables the user to become familiar with the operation of the EMG board and provides for preliminary testing of the EMG input circuitry. It displays the activity of each channel as either a "1" or a "0" on the screen. The Zenith beeps when a hit occurs. A brief message is also displayed telling the user on which channel the last hit occurred. In this manner, the user can determine the required force and length of tension which he needs to apply to have the computer recognize an input. It is also useful to determine how quickly a series of inputs can be given to the computer.

Program: MENUS

MENUS is a program which simulates the use of the system to control a fighter aircraft. This program is also listed in Appendix A. As the name implies, this program consists of a series of menus. The menus are arranged in a matrix format as shown in Table 1. The instructions on each menu are used to control various aspects of the plane's operation. Ten separate menus are used. The operation of the program is explained below.

There are four matrices which are initialized at the beginning of the program. The first is a string matrix which contains the word which will be printed on the monitor. The second is a numeric matrix which holds the

Menus used for display and speech.

FLIGHT CONTROL	RADAR	EMERGENCY	FIRE	SUB-FIRE
Increase Speed	Check Radar	Verify	Bravo 1	Hold Target
Decrease Speed	Target Position	Cancel	Bravo 2	Switch Off
Bank Left	Identify Target		Romeo 1	Switch On
Bank Right	Flight Control		Romeo 2	Go
Level Off	Fire		Flight Control	Stop Sequence
Radar	Emergency		Radar	
Fire			Emergency	
Emergency				

Menus used for speech only.

CHECK RADAR	TARGET POSITION	IDENTIFY TARGET		
No Target	Target Up	Target is Mig	Error	Select
Target Alert	Target Down		Release	
	Target Left		Launch	
	Target Right			
	Target In Position			

Table 1. Contents of Menus

number corresponding to the color to be used to display the word. The color of each word is used to determine if the instruction has been removed from the menu. The third contains the number of words to be spoken with each instruction. The fourth is a three dimensional string matrix which holds the hexadecimal addresses of the words in the VSM.

The row number of each column represents a different instruction. Only one instruction on one menu is active at any time. The computer keeps track of the current location in the matrix by the row and column numbers.

The program always has two options. The first allows you to move to the next instruction on the menu. This operation follows the flowchart shown in figure 19.

The second option selects the instruction which is currently active. If this option is taken, the computer first acknowledges the selection by saying "select". It then determines the proper function by checking the row and column numbers. Based on these numbers, the program branches to a subroutine. Once the subroutine is complete, the program returns to the EMG input algorithm.

The functions performed are only limited by the capabilities of the computer. The ability to control external circuitry is already shown by the speech board. Extending this control to power devices, motors, etc., is a simple process.

APPENDIX B

CIRCUIT BOARD SCHEMATICS

```
10900 '   Subroutine  to  simulate  radar  feedback;  when
          information is requested from the radar menu, this
          subroutine generates random feedback.

11000 OI=I
11003 ON OI GOTO 11005,11020,11040
11005 MENU=6:I=INT(RND*2+1)
11010 GOTO 11050
11020 MENU=7:I=INT(RND*5+1)
11030 GOTO 11050
11040 MENU=8:I=1
11050 GOSUB 10020
11060 I=OI:MENU=2:RETURN
```

```
1800 ' Subroutine to preform proper function
       when a "hit" is recognized.

1900 OI=I:OM=MENU:I=1:MENU=10:GOSUB 10000:I=OI:MENU=OM
2000 ON MENU GOTO 2010,2020,2030,2040,2050
2010 ON I GOSUB 3000,3000,3000,3000,3000,4200,4400,4300
2015 RETURN
2020 ON I GOSUB 11000,11000,11000,5100,4400,4300
2025 RETURN
2030 ON I GOSUB 400,4100
2035 RETURN
2040 ON I GOSUB 5000,5000,5000,5000,4100,4200,4300
2045 RETURN
2050 ON I GOSUB 3000,9000,8000,7000,4500
2055 RETURN
3000 LOCATE 20,Q:SCREEN,0:PRINT A$(I,MENU)+"      "
3010 RETURN
4100 CLS:MENU=1:Q=10:GOSUB 800:I=1:GOSUB 915:RETURN
4200 CLS:MENU=2:Q=10:GOSUB 800:I=1:GOSUB 915:RETURN
4300 CLS:MENU=3:Q=10:GOSUB 800:I=1:GOSUB 915:RETURN
4400 CLS:MENU=4:Q=10:GOSUB 800:I=1:GOSUB 915:RETURN
4500 CLS:MENU=4:Q=10:GOSUB 800:I=STOREI:GOSUB 915:
      GOSUB 9000:RETURN
5000 STOREI=I:MENU=5:Q=30:GOSUB 800:I=1:GOSUB 915:RETURN
7000 IF FLAG(STOREI)=3 THEN C(STOREI,4)=1 :ON STOREI
      GOTO 7020,7020,7030,7030
7010 OI=I:OM=MENU:I=1:MENU=9:GOSUB 10000:I=OI:MENU=OM:RETURN
7020 OI=I:OM=MENU:I=2:MENU=9:GOSUB 10000:I=STOREI:MENU=4:
      GOSUB 10000:GOSUB 4500:RETURN
7030 OI=I:OM=MENU:I=3:MENU=9:GOSUB 10000:I=STOREI:MENU=4:
      GOSUB 10000:GOSUB 4500:RETURN
8000 FLAG(STOREI)=3:GOSUB 3000:RETURN
9000 FLAG(STOREI)=1:RETURN

10000 '   This  is the VSP subroutine; to use  it,  set  the
          string  "AD$" to the address of the word you want.
          Example: 8000 is for alpha

10020 FOR K=1 TO NW(I,MENU)
10025 FOR L = 1 TO 4:P=ASC(MID$(AD$(I,MENU,K),5-L,1)):
        IF P>&H39 THEN P=(P AND &HDF)-&H37  ELSE P=P-&H30
10030 OUT VSP,64+P:NEXT L
10050 OUT VSP,SPK
10060 IF (INP(VSP) AND &H80) THEN 10060
10070 OUT VSP,RST:NEXT K
10080 RETURN
```

```
210  GOSUB 920

290  '    Algorithm to monitor muscle board and
          determine when a muscle is active.

300  X0HIT=0:X1HIT=0
302  OUT MUSC,3:OUT MUSC,0:INC=0
305  X=INP(MUSC):X0=X AND 1:X1 = (X AND 2)/2:INC=INC+1
310  IF (X0 OR X1) THEN 320 ELSE IF INC=20 THEN 300
      ELSE 305
320  IF (X0 AND X0HIT) THEN GOSUB 900 ELSE IF X0 THEN
      X0HIT=1:GOTO 302
330  IF (X1 AND X1HIT) THEN GOSUB 1900 ELSE IF X1 THEN
      X1HIT=1:GOTO 302
340  GOTO 300

390  '    End-of-program sequence

400  COLOR 7:SCREEN,0:CLS:END

790  '    Subroutine to print new menu to screen

800  FOR I= 1 TO M(MENU)
810  LOCATE 10+I,Q:SCREEN,0:COLOR C(I,MENU):PRINT A$(I,MENU)
820  NEXT I
830  RETURN

890  '    Subroutine to move to the new instruction

900  LOCATE 10+I,Q,:SCREEN,0:COLOR C(I,MENU):
      PRINT A$(I,MENU)
910  I=I+1:IF I>M(MENU) THEN I=1
915  IF C(I,MENU) = 1 THEN I=I +1:GOTO 915
920  LOCATE 10+I,Q,:SCREEN,1:COLOR C(I,MENU):
      PRINT A$(I,MENU)
930  GOSUB 10020
999  RETURN
```

Program listing: MENUS

```
1    '  Program name: MENUS
        This program uses the EMG conditioning board
        inputs to control a series of menus which
        simulate flight control.  This program uses
        the speech synthesis board.

2    '  This is the initialization routine. It sets up all
        port addresses, resets the speech board and
        initializes all menus. The first menu is then
        displayed with the first instruction active.

5    CLS
10   DIM C(10,10),A$(10,10),AD$(10,10,5),NW(10,10)
15   VSP=&H1F:RST=&H70:SPK=&H50:MUSC=&H3F
17   OUT VSP,RST
20   DATA 10
30   DATA 8,INCREASE SPEED,7,2,D495,19CC,DECREASE SPEED,7,
          2,9BF6,19CC,BANK LEFT,7,2,F342,B4AE,BANK RIGHT,7,
          2,F342,B50F,LEVEL OFF,7,1,C60C,RADAR,6,1,A102,
          FIRE,6,1,1D80,EMERGENCY,4,1,8D0B
40   DATA 6,CHECK RADAR,7,2,3601,A102,TARGET POSITION,7,2,
          8F13,3172,IDENTIFY TARGET,7,2,B902,8F13,
          FLIGHT CONTROL,6,2,FD55,200A,FIRE,6,1,1D80,
          EMERGENCY,4,1,8D0B
50   DATA 2,"VERIFY",4,1,A806,"CANCEL",7,1,A77C
60   DATA 7,BRAVO 1,7,2,0DE4,02FF,BRAVO 2,7,2,0DE4,047C,
          ROMEO 1,7,2,2814,02FF,ROMEO 2,7,2,2814,047C,
          FLIGHT CONTROL,6,2,FD55,200A,RADAR,6,1,A102,
          EMERGENCY,4,1,8D0B
70   DATA 5,HOLD TARGET,6,2,B364,8F13,SWITCH OFF,2,2,3721,
          13C5,SWITCH ON,6,2,3721,9221,GO,4,1,1788,
          STOP SEQUENCE,7,2,1F41,AFE2
75   DATA 2,D,0,2,9E91,8F13,D,0,2,8F13,9511
80   DATA 5,D,0,2,8F13,2BFD,D,0,2,8F13,DA99,D,0,2,8F13,
          B4AE,D,0,2,8F13,B50F,D,0,3,8F13,7B6A,3172
85   DATA 1,D,0,5,8E8D,8F13,2C28,8E8D,94A5
90   DATA 3,D,0,1,9D7E,D,0,1,A4F9,D,0,1,EF3B
95   DATA 1,D,0,1,93B9
100  READ N
110  FOR I = 1 TO N
120  READ M(I)
130  FOR J=1 TO M(I)
140  READ A$(J,I),C(J,I),NW(J,I)
142  FOR K = 1 TO NW(J,I)
144  READ AD$(J,I,K):NEXT K
150  NEXT J,I
160  MENU=1:Q=10
170  GOSUB 800
200  I= 1
```

Program listing: INP2CH

```
1     '  Program name: INP2CH (INPut Two CHannels)
         This program monitors the output of the
         EMG Conditioning Board and indicates to
         the user the activity on each channel.

5     CLS
10    MUSC=&H3F
12    X0HIT=0:X1HIT=0
15    OUT MUSC,3:OUT MUSC,0:INC=0
20    X=INP(MUSC):X0=X AND 1:X1=(X AND 2)/2:INC=INC+1
25    LOCATE 1,1:PRINT X0;"      ";X1;
30    IF (X0 OR X1) THEN 40 ELSE IF INC=20 THEN 12 ELSE 20
40    IF  (X0  AND X0HIT) THEN PRINT "ch 0 good" ELSE  IF  X0
       THEN X0HIT=1:GOTO 15
50    IF  (X1  AND X1HIT) THEN PRINT "ch 1 good" ELSE  IF  X1
       THEN X1HIT=1:GOTO 15
60    BEEP:GOTO 12
```

Program listing: SPK-WORD*

```
1     '  Program name: SPK-WORD  (SPeaK WORD)
         This program prompts the user to input
         a four digit hexadecimal number which
         represents an address of a word in the
         VSM.  The word is spoken and a prompt
         is given for another address.

3     VSP=&H1F:RST=&H70:SPK=&H50:LA=&H40
5     OUT VSP,RST
10    CLS:INPUT  "ADDRESS  TO  OUTPUT";AD$:IF  AD$="" THEN
       AD$=OLDAD$
20    FOR I=1 TO 4:Q=ASC(MID$(AD$,5-I,1)):IF Q>&H39 THEN
       Q=(Q  AND &HDF)-&H37 ELSE Q=Q-&H30
30    AD=AD+Q*16^(I-1):OUT VSP,64+Q:NEXT I
40    LOCATE 15,1:PRINT HEX$(AD);
50    OUT VSP,SPK
60    IF (INP(VSP) AND &H80) THEN 60
70    OUT VSP,RST:AD=0:OLDAD$=AD$:GOTO 10
```

* All Software is written in Z-BASIC with operating system Z-DOS/MS-DOS release 1.01, version 1.25 and Z-DOS/MS-DOS BIOS release 1.00, version 1.10.

The system can also be improved by making it more interactive with the user. For example, the user may be given the option to change the limit of the counter used in the EMG input algorithm. Another option could change the threshold value of the comparator on the EMG conditioning board. This type of interaction would allow the user to fine tune the system to provide maximum performance for a variety of conditions.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Summary

The final working system shows the capability of using myoelectric signals to control a computer. This serves as a direct link between the human operator and the computer. Using this link, systems can be developed which capitalize on the strengths of both human intelligence and computer efficiency.

Recommendations

The myoelectric control system will need to be upgraded for operation in a G force environment. This section discusses a few suggestions to improve the overall operation the the system.

A parallel coding technique using signals from many groups of muscles will probably be necessary. In addition, this parallel coding should use muscle groups which are unrelated. This combination will decrease the chances of a natural or reflex movement being recognized as a input. For example, blinking one eye would be more advantagious than blinking both eyes because blinking both eyes is a reflex.

Left	Right	Effect
0	0	None
0	1	Scan
1	0	Select
1	1	First Arrival

Table 2. Coding for Demonstration

Results

This test has been run on different people a number of times. The outcome of all tests has been favorable. In each case, the operator was able to maintain control over both the Pong game and the myoelectric control system. To test for possible noise effect on the system, the operator was told to do nothing. The system was running for over a half hour under these conditions with no spurious input recognized. In addition, the operator can make slow easy movements without having the system react.

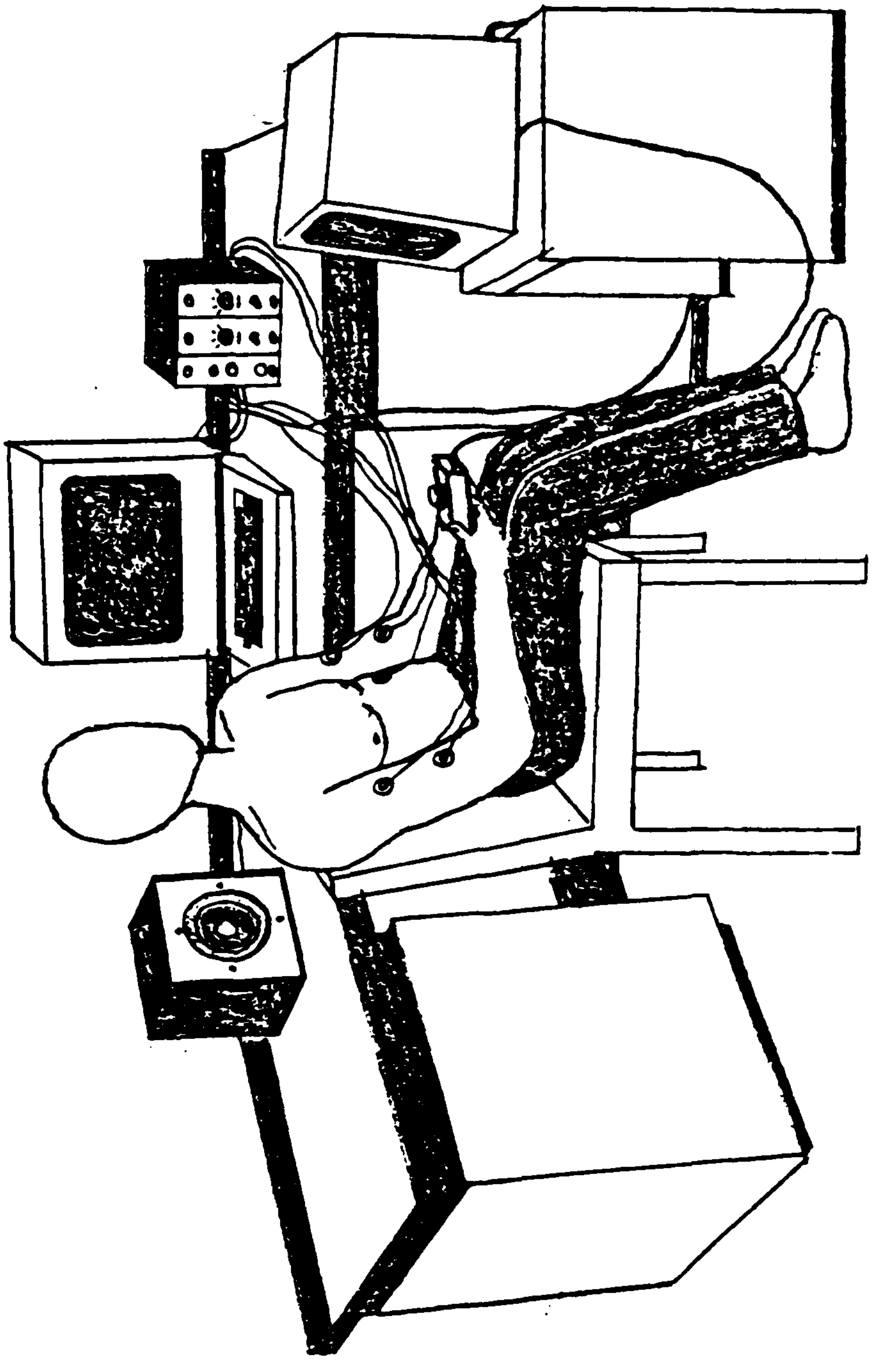

Figure 20. Demonstration Setup

CHAPTER VI

EXPERIMENTATION

The experiments described here are done to test two aspects of the myoelectric control system. First, an experiment is performed to show that the user could control the computer's operation without error. The second test is to show that the user can be performing another task at the same time. Both these tests are satisfied by the demonstration outlined here.

Procedure

A visual look at the test conditions is shown in figure 20. The user is hooked up to the myoelectric control system and also holds the controls to a simple Pong game. The object of the test is to operate the Pong game to the best of the user's ability and still be able to control the myoelectric control system. During the test, the user is told what function the computer is to perform. The user must then be able to get the computer to react in the desired manner without missing a shot in the pong game. The coding of the system is shown in Table 2.

These functions are also enhanced by the computer's ability to act as an expert system. For example, the MENUS program can detect errors in the required sequence to fire an armament and inform the user of his mistake. This program also remembers which armaments were fired and removes them from the menu.

The computer can also monitor other input devices which could aid in the operation of the entire system. This activity is simulated by the MENUS program with the subroutine to provide radar feedback. This subroutine could be replaced by a system to monitor the actual radar. The computer can then use this input to assist the pilot.

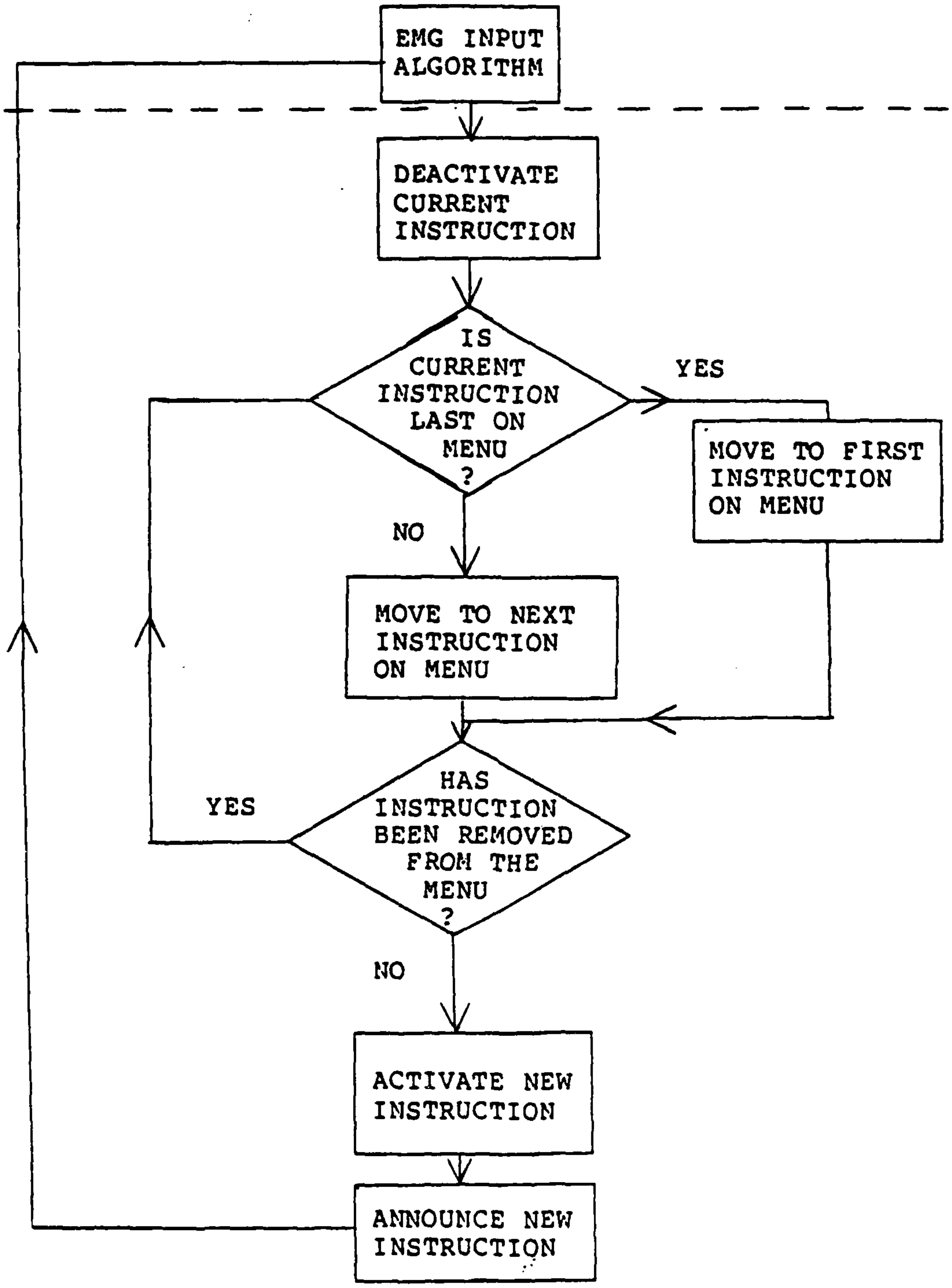

Figure 19. Menu Scan Flowchart

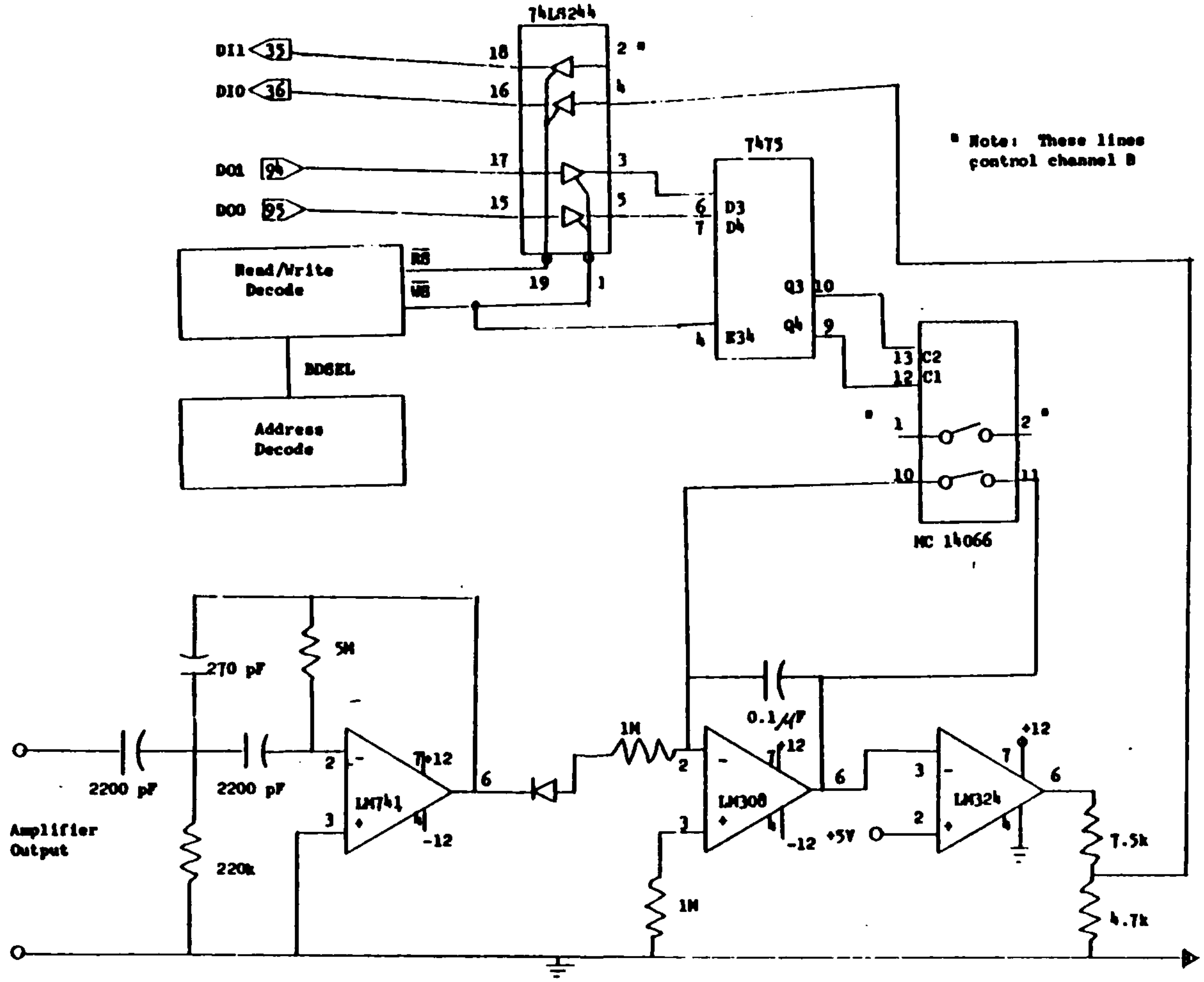

Figure B1. EMG Conditioning Board Schematic

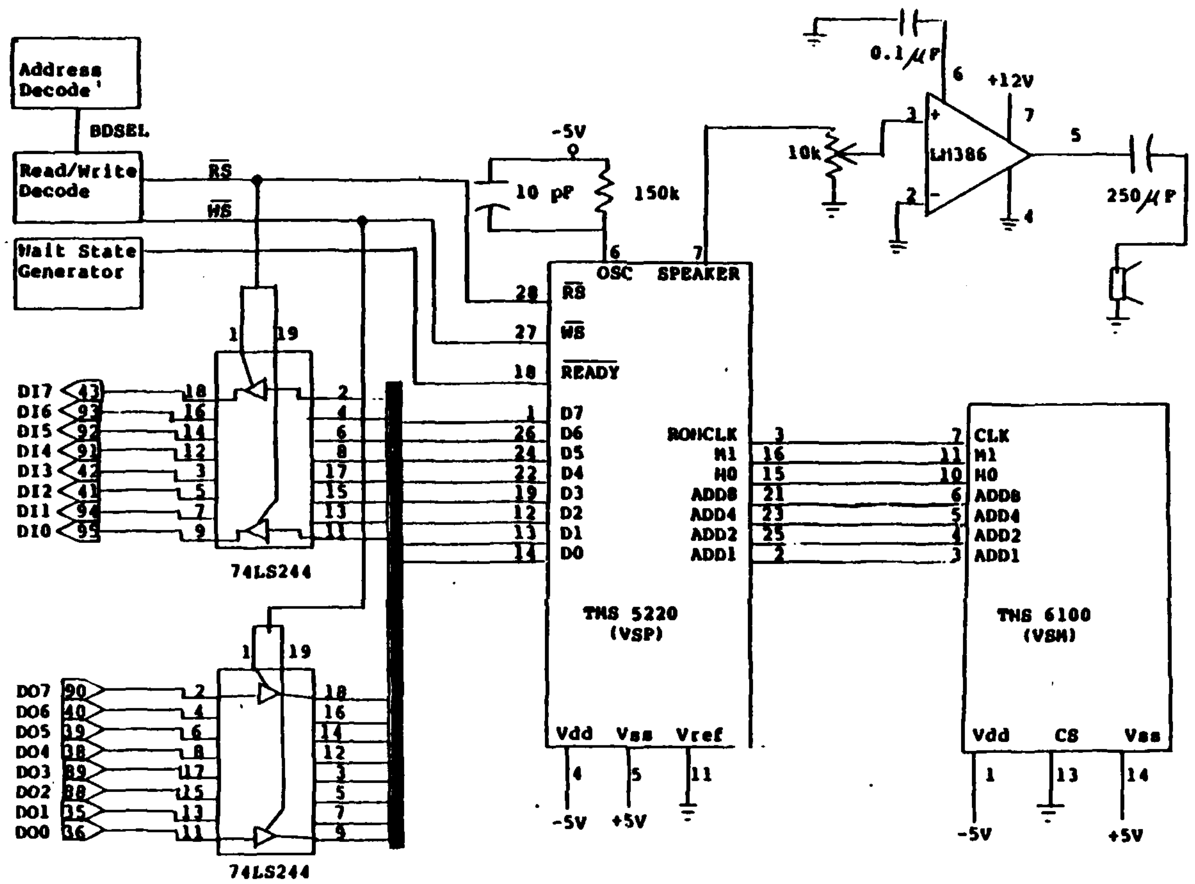

Figure B2. Speech Synthesis Board Schematic

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